EFFECTS OF WEATHER ON ACCIPITER MIGRATION IN SOUTHERN NEVADA

by
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Abstract

Migrating Sharp-shinned Hawks (*Accipiter striatus*) and Cooper's Hawks (*A. cooperii*) were observed along a forested ridge surrounded by desert in the Spring Mountains of southern Nevada from 31 August until 17 October 1980. Greatest numbers of accipiters were counted on days cold fronts passed through our study area; however, fronts typically separated relatively homogeneous air masses, and passage produced no perceptible or consistent changes in surface weather variables (as measured at our study site). Analysis indicated that perceived migrant abundance, although strongly associated with cold front passage, was not related to surface weather conditions as many other studies have suggested. The "extra" accipiters observed on front days appeared between mid-morning and late afternoon. This is the period of the day when accipiters and other hawks frequently migrate at high altitudes riding thermal updrafts. We believe post-frontal atmospheric stability and strong winds aloft confined thermal activity to a narrow zone in the lower atmosphere on front days, which resulted in more accipiters migrating at lower altitudes. Increased counts probably resulted because: (1) a higher proportion of the daily flight occurred within visible range; (2) more accipiters may have sought lift from updrafts along mountain ridges as an alternative to thermal updrafts; and (3) migrating accipiters may have become reluctant to cross inhospitable deserts at lower altitudes, and instead directed flights over boreal forests along ridgetops. We suggest post-frontal atmospheric conditions may similarly affect raptor migration elsewhere, and future studies should more thoroughly investigate the role of weather in influencing the height of migration.

Introduction

Autumn raptor migration has been studied in few parts of North America, notably several localities in the east and midwest where large numbers of raptors concentrate under certain conditions (Heintzelman 1975). At these sites raptor counts are typically greatest following the passage of a cold front when surface winds switch to a westerly or northerly direction, barometric pressure rises, temperature falls, the sky clears, and often, wind speed increases (Mueller and Berger 1961, Haugh 1972). Many researchers have postulated a direct relationship between frontal changes in these weather variables, either singly or additively, and the magnitude of hawk migration (Mueller and Berger 1961, Haugh 1972, Hoffman 1981).

Strong cold front activity is not universal throughout North America in autumn. For

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For example, at low latitudes in the western United States autumn is a fairly stable meteorological period (Brown 1974, Sellers and Hill 1974) and most cold fronts separate relatively homogeneous air masses (hence are "weak"). Accordingly, many of the surface weather effects noted with front passage further north are absent. In an attempt to determine how weather influences raptor migration in this region, we observed migrating Sharp-shinned Hawks and Cooper's Hawks in southern Nevada for the bulk of the autumn migration period in 1980. This paper summarizes data collected and presents findings which, we believe, help explain the relationship between raptor migration and cold front passage.

Study Area

Observations were made from Potosi Mountain (Potosi), located 48 km west of Las Vegas in Clark County, Nevada (Fig. 1). Potosi is the southernmost peak in the Spring Mountains (Springs) and rises sharply out of a pass to an elevation of 2592 m, forming a narrow north-south ridge for about 6 km.

Like other mountain ranges in southern Nevada, the Springs rise abruptly from low elevation (900 m) valleys. Annual precipitation ranges from about 11 cm in valleys to 50 cm in mountains (Brown 1974). Vegetation typical of Transition, Upper Sonoran, and Lower Sonoran Life-zones occur in the area in broadly overlapping altitudinal zones. Boreal and Rocky Mountain conifer forests of bristlecone pine (*Pinus aristata*), limber pine (*P. flexilis*), and ponderosa pine (*P. ponderosa*) occur along ridgetops above 2430 m elevation. Cold temperate Great Basin conifer woodlands of pinyon pine (*P. Monophylla*) and juniper (*Juniperus* spp.) dominate at elevations between 2740 m and 1830 m. Below 1830 m warm temperate Mohave desert scrub associations of joshuatree (*Yucca brevifolia*) and creosotebush (*Larrea tridentata*) predominate (vegetation formation follow Brown *et al.* 1979, plant names follow Lehr 1978). Boreal forests in the Springs and nearby Sheep Mountains are isolated from other tracts of similar vegetation by at least 160 km of Upper and Lower Sonoran Life-zone vegetation (Fig. 1).

Methods and Data Treatment

Raptors were counted, captured, and banded from a blind in a clearing atop Potosi. Counts included all accipiters caught or enticed into the area as well as nonresponsive individuals. We initiated observations on 31 August 1980 and continued daily counts until 17 October 1980. Raptors were identified to species as conditions allowed and tallied by hour on daily count forms. Weather conditions were recorded at the start and close of each observation day and at least once each 2 h between start and close. Temperature, percent cloud cover, wind speed, wind direction, and barometric pressure were determined at each reading. Raptor counts and weather data were obtained for 34 complete days (i.e. beginning at 0800 h and continuing until 1700 h).

Using these and other data available to us we calculated three variables describing the accipiter migration and 14 variables describing weather conditions for each complete observation day (Table 1). We then placed each day into one of four groups according to prevailing wind direction (i.e. days dominated by northerly winds in one group, easterly winds in another, southerly in another, and westerly in another) and searched for bivariate and multivariate correlations between count and weather variables within groups. We also compared average daily counts between groups. Sample sizes were sufficient to yield meaningful conclusions for only two groups; days with southerly (n= 17 days) and westerly (n= 12 days) winds. Accordingly, we confined analysis of migration/weather relationships to this 29 day sample.

All analyses were performed on a Honeywell 6680 computer using STATPAC statistical packages with probability levels of $\alpha = 0.05$. Relations between two sets of variables were tested using product-moment correlation coefficients. Comparisons between means of two populations were conducted using the t-test (Sokal and Rohlf 1969) which requires no assumption of homogenity of variance nor equal sample sizes. Multivariate trends in weather data were determined using Principle Component Analysis (PCA). Care was taken to scale variables properly for PCA. PCA reduces a set of n raw variables (in our case, weather variables) to n components; each component consisting of a unique set of intercorrelated raw variables. In a PCA components are ranked so that each successive component accounts for a smaller proportion of total variance in the original data set. In most cases the first three components cumulatively account for 60 to 80 percent of the variance and additional components can be ignored (Levins 1968, Green 1974, Johnson 1977, Rotenbury 1978, Rotenbury and Weins 1980). In our analysis the first three components defined multifactorial gradients in total weather condition (as limited by the scope of our measurements). Component scores were calculated for each south and west wind day, and days were plotted along component axes. By comparing TAC on days falling in different positions along component axes (i.e. ordinating in different regions of the three-dimensional space), it was possible to assess the relationship between accipiter counts and general weather conditions.

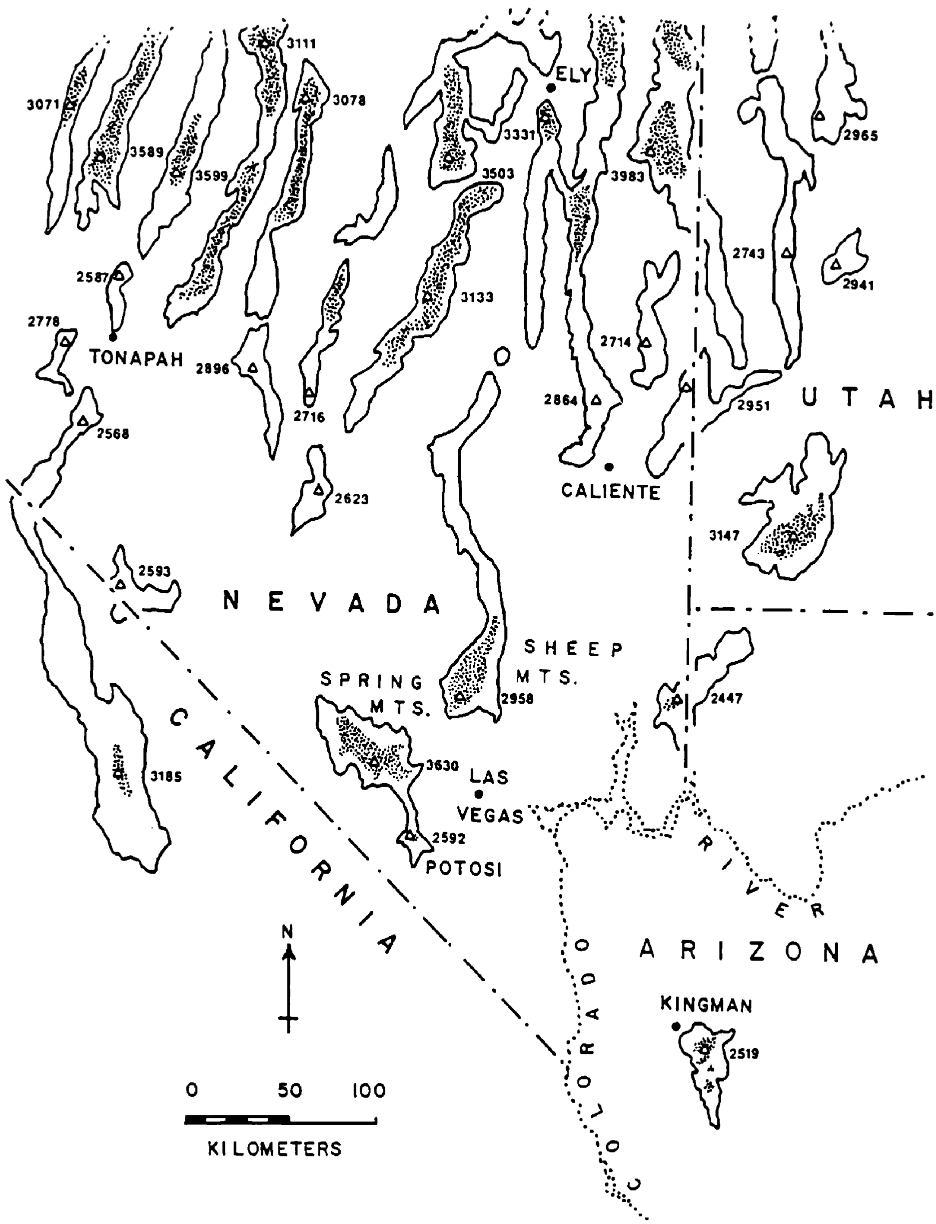

Fig. 1. Map of southern Nevada showing position of Potosi in relation to other physiographic features. Ranges with peaks over 2400 m are outlined (high peaks are marked for reference), and stippled areas delineate boreal islands of montane conifer forest vegetation.

Table 1 Description of accipiter count and weather variables calculated for each complete observation day.

No.	Code	Code
1.	Mean number total accipiters observed per h between 0800h and 1700	TAC
2.	Mean number Sharp-Shinned Hawks observed per h between 0800h and 1700h	TACST
3.	Mean number Cooper's Hawks observed per h between 0800h and 1700h	TACCO
4.	Maximum temperature (°F)	MXTEMP
5.	Temperature diversity[a]	HTEMP
6.	Average barometric pressure (cmHg)	AVBAR
7.	Barometric pressure diversity[a]	HBAR
8.	Average cloud cover (percent)	AVCC
9.	Cloud cover diversity[a]	HCC
10.	Equitability of cloud cover[b]	ECC
11.	Average wind speed (km/h)	AVWS
12.	Wind speed diversity[a]	HWS
13.	Equitability of wind speed[b]	EWS
14.	Prevailing wind direction	-
15.	24h barometric pressure change (cmHg)	-
16.	24th change in TAC	-
17.	Cold front passage[c]	-

[a]Calculated using the formula given in Shannon and Weaver (1949);

$$H = \sum_{i=1}^{s} P_i \ln P_i;$$

where Pi= proportion of readings in the ith measurement subdivision, s= the total number of subdivisions occupied, and H= the diversity index (HTEMP, HBAR, HCC, or HWS). For HTEMP each subdivision was 5°F. For HBAR each subdivision was 0.13 cmHg. For HCC each subdivision was 20 percent. For HWS each subdivision was 16 km/h.

[b]Calculated using the formula given in Power (1971);

$$E = H/H\max,$$

where H=HCC or HWS, and Hmax= lns, the maximum possible diversity index for s occupied subdivisions.

[c]Determined from NOAA Daily Weather Charts.

Results

Count Totals and Chronology of Migration

A total of 359 Sharp-shinned Hawks, 215 Cooper's Hawks, and 67 unidentified accipiters were observed. Accipiter counts varied from day to day in a series of peaks and troughs (Fig. 2). The mean interval between peaks for Sharp-shinned Hawks was 3.00 ± 1.04 days (1 SD). The mean interval for Cooper's Hawks was 2.91 ± 0.94 days. Intervals did not differ significantly between species ($p > 0.05$).

Seventy-two percent of Cooper's Hawks were observed during the first three weeks of September, with a noticeable peak between 10 and 19 September. Sharp-shinned Hawk migration appeared to increase during the first 10 days of September and remained relatively constant thereafter. Although observations did not cover the entire migration period for either species, Sharp-shinned Hawks appeared to migrate over a longer period of time than Cooper's Hawks.

Weather and Intensity of Observed Migration

Component patterns resulting from PCA for west wind days are summarized in Table 2, and the ordination of observation days is shown in Fig. 3. The first component described a gradient (from positive to negative in Fig. 3) from warm, wide ranging temperature; steady pressure; mostly clear skies; and light winds to low steady temperature; unsteady pressure; mostly cloudy skies; and strong winds. The second component described a gradient (from positive to negative in Fig. 3) from gusty to steady winds. The third component described a gradient (from positive to negative in Fig. 3) from steady sky conditions (i.e. completely overcast to completely clear) to variable sky conditions. Seven of eight west wind days with high TAC received positive scores on the first component, and six received negative scores on the third component. With one exception, days with low TAC received negative scores on the first component. This suggests that high TAC on west wind days was associated with warm, fair to partly cloudy weather, and light to moderate winds. Bivariate analyses supported this conclusion. TAC was negatively correlated with HBAR ($r=-0.53$ $p < 0.05$), AVCC ($r=-0.65$ $p < 0.05$) and HCC ($r=-0.72$ $p < 0.01$).

Component patterns resulting from PCA for south wind days are summarized in Table 3, and the ordination of observation days is shown in Fig. 4. The first component described a gradient (from positive to negative in Fig. 4) from warm temperature; high pressure; mostly clear skies; and steady winds to cool temperature; low pressure; mostly cloudy skies; and gusty winds. The second component described a gradient (from positive to negative in Fig. 4) from variable sky conditions and light winds to steady sky conditions and strong winds. The third component described a gradient (from positive to negative in Fig. 4) from wide ranging to steady temperature. Days with high TAC were relatively evenly distributed along all component axes. Bivariate analyses indicated there were no significant correlations between TAC, TACST, or TACCO and any of the weather variables used in PCA ($p > 0.05$ for all).

The direction and magnitude of 24 h changes in barometric pressure were not significantly correlated with changes in TAC regardless of wind direction ($n=34$ days) ($r=-0.06$, $p > 0.05$). Accordingly, a falling or rising barometer did not appear to influence count totals. There was, however, a significant difference in mean TAC and TACST between south and west wind days; both variables were greater with south winds ($p < 0.01$). Mean TACCO was also greater with south winds, but the difference was not statistically significant ($p > 0.05$).

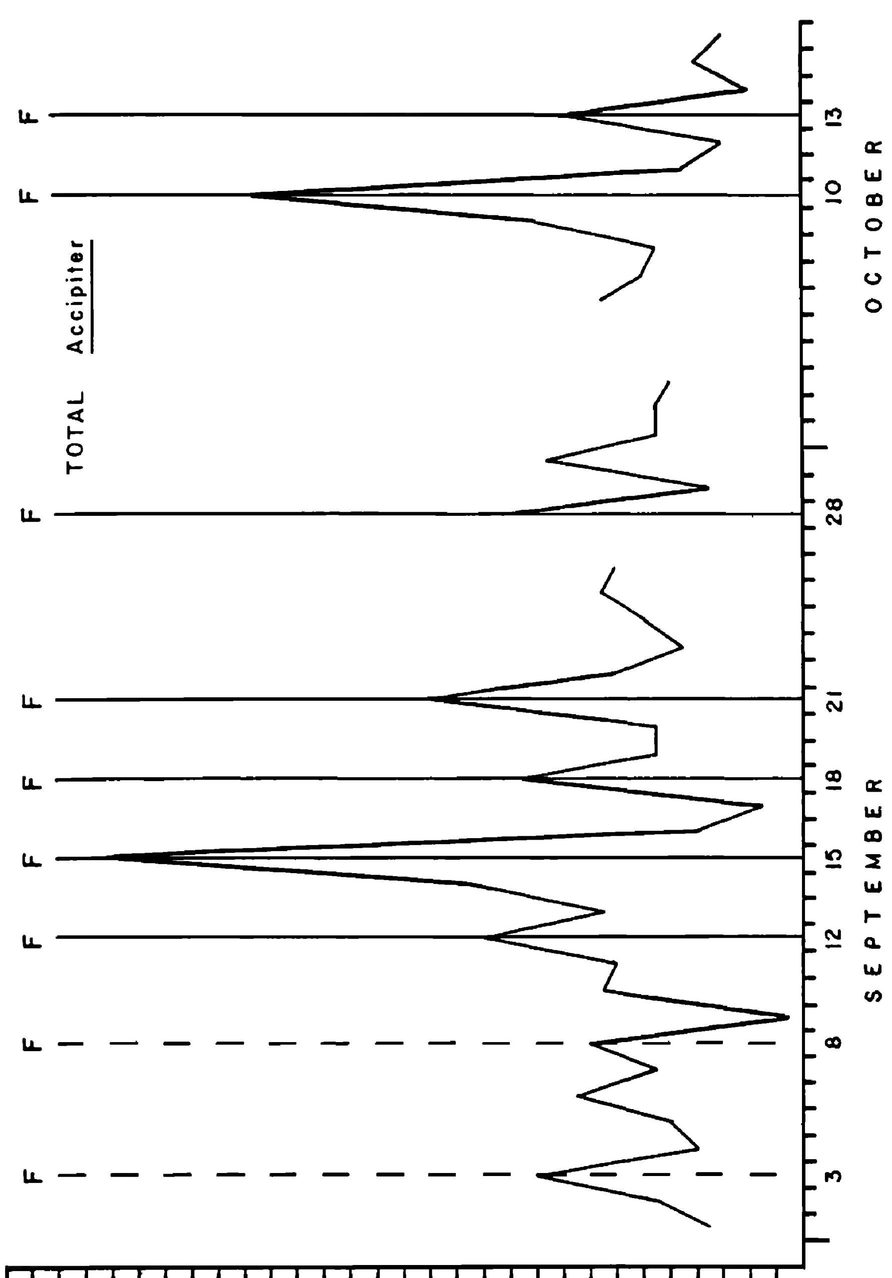

Fig. 2. Total accipiter counts (Sharp-shinned Hawks + Cooper's Hawks + unidentified accipiters) for complete observation days (0800h to 1700h). Vertical lines marked F indicate passage of a cold front. Dashed lines indicate front days not analyzed due to incomplete weather measurements.

Table 2. Factor loadings of weather principal components for days with west winds. Only significantly correlated ($p < 0.05$) values shown.

Component :	I	II	III
Eigenvalue :	5.09	1.48	1.26
% Variance :	50.89	14.80	12.64
Σ % Variance :	50.89	65.69	78.34
Variable			
Maximum Temperature (MXTEMP)	.92		
Temperature Diversity (HTEMP)	.79		
Average Barometric Pressure (AVBAR)			
Barometric Pressure Diversity (HBAR)	-.76		
Average Cloud Cover (AVCC)	-.92		
Cloud Cover Diversity (HCC)	-.88		
Equitability of Cloud Cover (ECC)			.76
Average Wind Speed (AVWS)			
Wind Speed Diversity (HWS)	-.73	.62	
Equitability of Wind Speed (EWS)		-.81	

There is strong evidence that differences in accipiter counts between south and west wind days were not related to wind direction per se, but resulted from a strong positive relationship between count totals and cold front passage (Fig. 2). Days of cold front passage at Potosi were always dominated by southerly winds, and mean TAC was significantly greater on frontal compared with nonfrontal south wind days ($p < 0.05$).

Most cold fronts which, according to daily weather charts, passed Potosi were weak and produced no perceptible change in weather conditions on Potosi. Furthermore, weather conditions on front days were highly variable. For example, front days were evenly distributed along all three south wind PCA components; of seven front days, three received positive scores and four negative scores on the first component, three were positive and four negative on the second, and three were positive and four negative on the third (see Fig. 4). This suggests accipiter counts were positively influenced by front passage regardless of weather conditions at our study site.

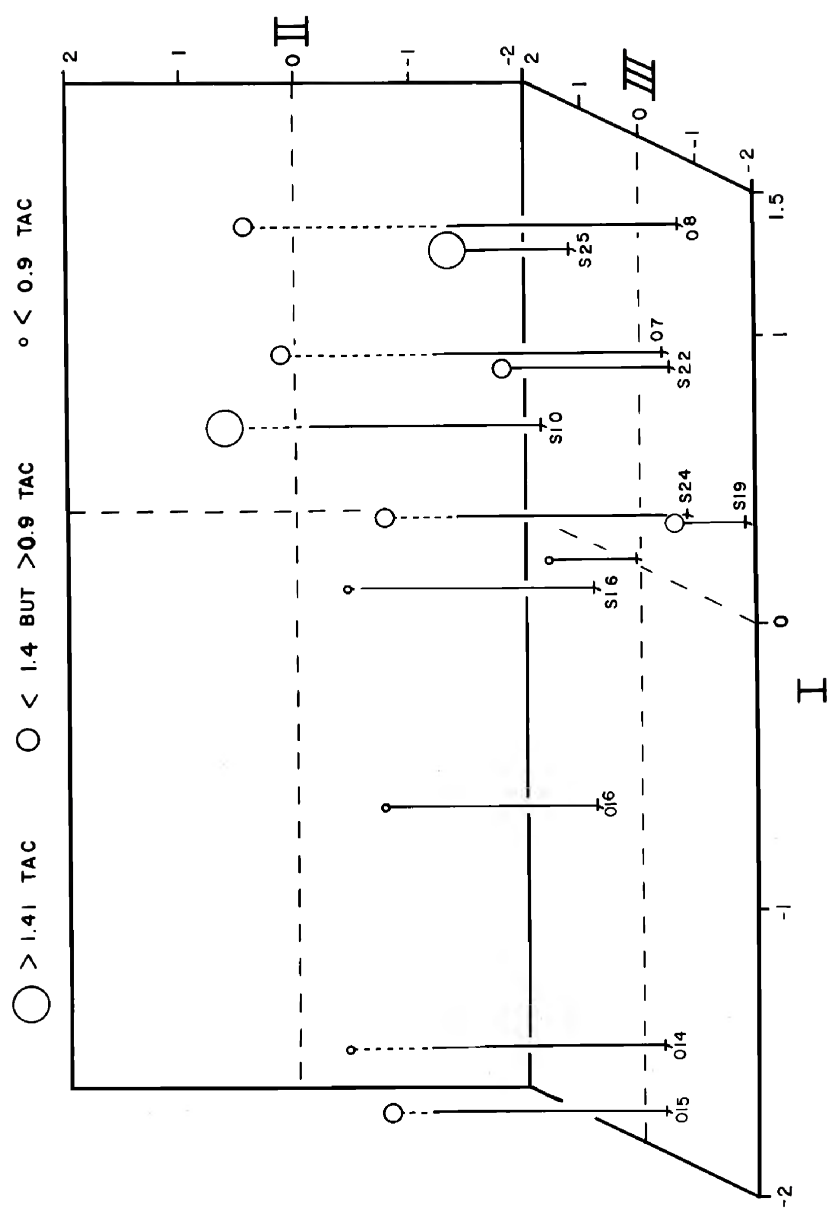

Fig. 3. Graphic ordination of west wind observation days on weather principle component axes. Each pin represents one observation day, and dates are marked at the base of each pin where S = September and O = October. Pinhead size indicates relative TAC (Total Accipiter Abundance, or mean number of total accipiters observed per hour) as defined in the key above graph. Small dashed lines on pins indicate positive scores on component II. Large dashed lines separate quadrates. See text and Table 2 for interpretation of the axes.

Table 3. Factor loadings of weather principal components for days with south winds. Only significantly correlated ($p < 0.05$) values shown.

Component	:	I	II	III
Eigenvalue	:	3.57	2.21	1.26
% Variance	:	35.75	22.06	15.20
Σ % Variance	:	35.75	57.81	73.01
Variable				
Maximum Temperature (MXTEMP)		.84		
Temperature Diversity (HTEMP)				.92
Average Barometric Pressure (AVBAR)		.66		
Barometric Pressure Diversity (HBAR)				
Average Cloud Cover (AVCC)		-.63	.60	
Cloud Cover Diversity (HCC)			.72	
Equitability of Cloud Cover (ECC)		-.71		
Average Wind Speed (AVWS)		-.67	-.64	
Diversity of Wind Speed (HWS)		-.68	-.64	
Equitability of Wind Speed (EWS)				

Although accipiter counts showed a consistent daily rhythm, the distribution of observations differed between front and nonfront south wind days (Fig. 5). On non-front days most Cooper's Hawks appeared in the morning, and a moderate proportion of Sharp-shinned Hawk observations occurred prior to 0930 h. On front days, however, most Cooper's Hawks were observed after mid-day and a relatively small proportion of Sharp-shinned Hawks were seen in the early morning. This indicates that for both species, increased counts on front days were the result of more individuals appearing during the late morning and afternoon hours rather than an overall increase in migrant numbers throughout the day.

Discussion

Accipiter migration occurred on all days with generally fair weather. High counts, however, were strongly associated with cold front passage and did not appear related to weather conditions on Potosi. Although it is possible that accipiters responded to changes in barometric pressure or temperature too small to be detected on our instruments, Mueller and Berger (1961) present evidence that such perception is unlikely in raptors. This leads us to conclude other factors associated with cold fronts affected migration. The most logical alternatives are that: (1) cold front passage caused changes in surface weather conditions to the north of Potosi, and these changes produced an increase in the volume of movement into our study area (i.e. more hawks were aloft over Potosi); or (2) front passage produced changes in atmospheric weather conditions (rather than changes in weather on Potosi) which altered flight conditions and resulted in more accipiters passing within our range of vision.

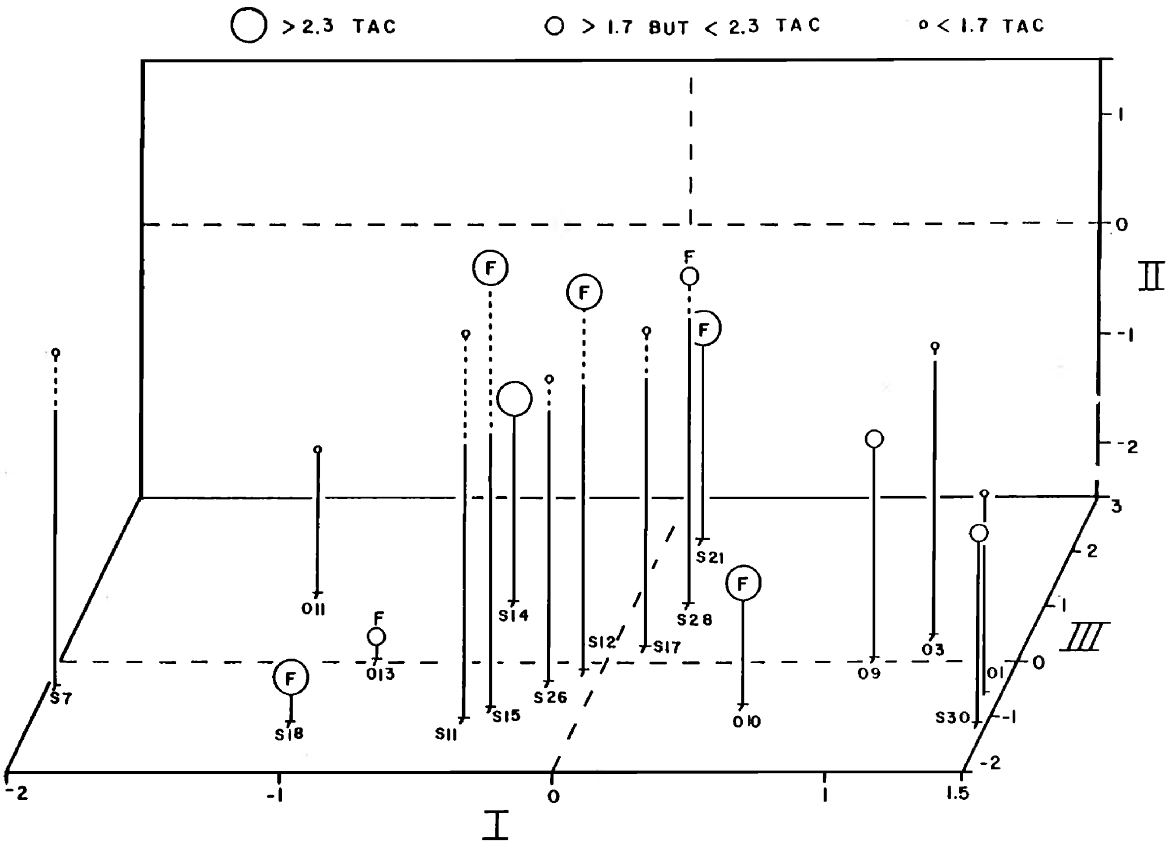

Fig. 4. Graphic ordination of south wind observation days on weather principle component axes. Each pin represents one observation day, and dates are marked at the base of each pin where S = September and O = October. Pinhead size indicates relative TAC (Total Accipiter Abundance, or mean number of total accipiters observed per hour) as defined in the key above graph. Small dashed lines on pins indicate positive scores on component II. Large dashed lines separate quadrates. Front days are marked F. See text and Table 3 for interpretation of the axes.

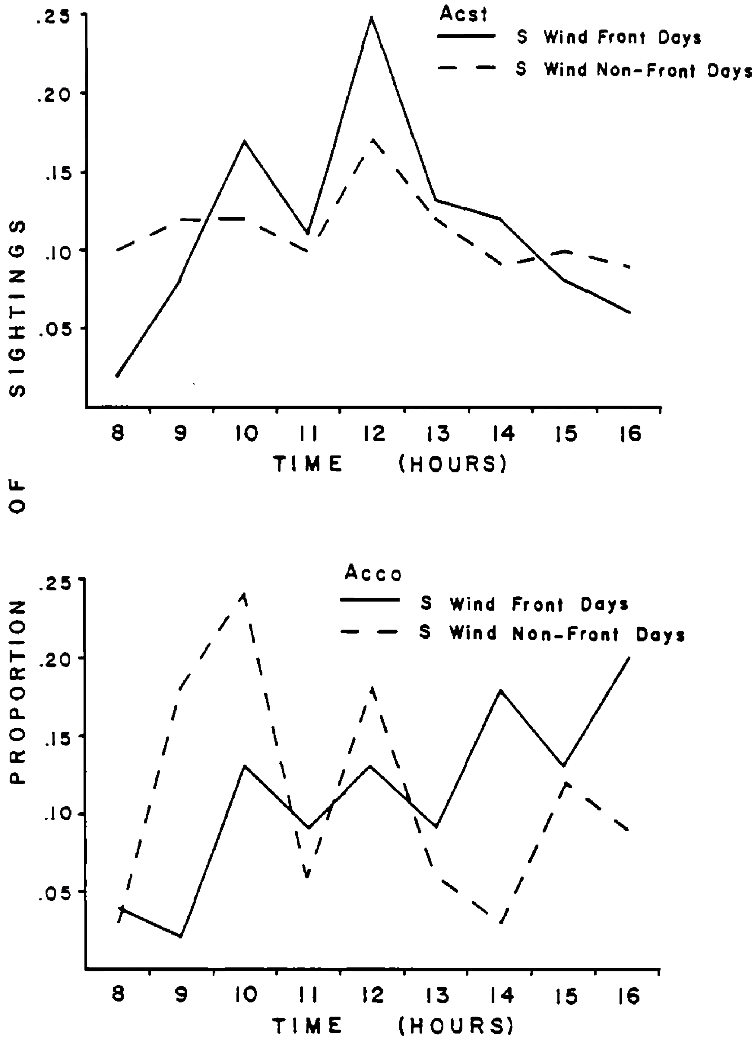

Fig. 5. Proportion of total number of Sharp-shinned Hawks (ACST) and Cooper's Hawks (ACCO) observed by hour on south wind days when cold fronts passed Potosi (S wind front days) and non-frontal south wind days (S wind non-front days).

We doubt the former factor was responsible. If the volume of accipiter movement increased further north it is unlikely all migrants from all affected latitudes would reach Potosi on the same day as the front; our counts would have been higher than normal not only on front days, but following days as well (see Fig. 2). Furthermore, if more hawks were aloft over Potosi on front days, counts for all periods of the day (rather than only specific hourly periods) should have been greater than normal (Fig. 5). On the other hand, the latter observation is perhaps the best evidence that local atmospheric conditions were responsible. Migrant raptors, including accipiters, are known to travel at high altitudes (above the range of visual detection by ground observers), and such flights may be particularly common in areas like southern Nevada where inhospitable expanses (deserts) must be crossed (Allen and Peterson 1936, Deelder and Tinbergen 1947, Evans and Lathbury 1973, Richardson 1975). High altitude flights by soaring birds are typically associated with (or initially depend upon) thermal updrafts and usually occur between mid-morning and late afternoon when thermal activity is greatest (Pennycuick 1979, Heintzelman 1975, Miller 1976, Thiollay 1980). The "extra" accipiters observed on front days at Potosi appeared almost exclusively during this period of the day, which suggests atmospheric conditions behind fronts resulted in a greater proportion of a normally high and/or dispersed mid-day flight occurring within visible range. We believe atmospheric conditions behind fronts forced accipiters to migrate at lower than normal altitudes.

Although we are uncertain how flight conditions changed, at least two meteorological factors may have been involved. Thermals form when a parcel of air near the surface becomes warmer than the surrounding air and begins to rise. The parcel continues to rise until it is sheered and disseminated by winds or, through radiation and intermixing, it reaches the same temperature as the air around it (Miller 1976). Accordingly, thermals are particularly prevalent and attain greatest heights on days when the atmosphere is unstable (i.e. when temperature decreases steadily with altitude) and winds aloft are light (Miller 1976). At the leading edge of a cold front, however, warm air is displaced up and over cool air near the surface; the actual front slopes back over the cool air mass. Behind the leading edge of the front, where the cool air is overlain by warm air, rising thermal parcels probably cease vertical motion upon penetrating the warm air layer. The resultant decrease in vertical motion produces stronger winds aloft (although not necessarily at the surface) because frictional drag with the surface is reduced (Miller 1976). These conditions could act to confine thermal activity to (and hence, force raptors to travel in) a relatively narrow altitudinal zone near the surface following front passage.

A simple lowering of flight height for any reason would increase the proportion of migrants visible to observers on the ground. In addition, however, it could increase use of ridges by migrating accipiters. Horizontal winds striking the sides of a ridge are deflected upward (declivity currents), and raptors make use of these currents to remain aloft and expedite passage on migration (Heintzelman 1975). On days when thermal activity was unrestricted migrants probably traveled directly across deserts around Potosi by gliding from thermal to thermal after mid-morning. With reduced high altitude thermal activity on front days, accipiters may have been forced to rely upon declivity currents to remain aloft throughout the day. It is also possible accipiters were reluctant to cross deserts at low altitudes; birds are often hesitant to cross inhospitable terrain at other than great heights (Deelder and Tinbergen 1947). This might further increase migrant use of ridges, which supported forest and woodland vegetation typical of accipiter habitat in the west (Reynolds 1982).

Although increased wind speeds have long been known to cause birds to fly at lower altitudes (Deelder and Tinbergen 1947), we know of no studies which suggest that a decrease in the altitude of migration behind fronts may be the initial factor contributing to high raptor counts at various autumn lookouts. Many researchers have implied that maximal numbers of hawks migrate behind fronts, and post-frontal surface weather conditions and geography act to concentrate migrants at particular locations (Mueller and Berger 1961 and 1967, Heintzelman 1975). Although radar studies have confirmed that large numbers of hawks are aloft following passage of many cold fronts, comparable or larger flights of some species occur unassociated with typical post-frontal weather and at altitudes and/or locations where they are indiscernible from usual lookouts (Robbins 1956, Evans and Lathbury 1973, Richardson 1975). We suggest that strong raptor movements probably occur during fair weather regardless of cold front activity in autumn, and typically at high altitudes where mountain updrafts are not influential and short water and desert crossings are not prohibitive. The volume of movement is probably more closely associated with the direction of winds aloft (Richardson 1975) and/or, as our findings indicate, thermal activity. Behind cold fronts, however, our data suggests flight may be restricted to lower altitudes. Under these conditions migration probably becomes more visible and concentrations appear because: (1) updrafts along ridges are sought out as an alternative to thermals; and (2) hawks become reluctant to cross expanses of atypical or unsuitable habitat. Although speculative, our findings point out the possibility that autumn raptor concentrations may be merely temporary glimpses of a nearly continuous and largely invisible movement. Analysis of raptor migration data should be conducted with this possibility in mind, and more intensive study of the affects of atmospheric weather conditions on both raptor and bird migration in general is warranted.

Acknowledgements

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HAWK MOUNTAIN RESEARCH AWARD. The Board of Directors of the Hawk Mountain Sanctuary Association announces its annual award for raptor research. Students wishing to apply for the $500 award should submit a description of their research program, a curriculum vita, and two letters of recommendation by 30 September 1983 to James J. Brett, Curator, Hawk Mountain Sanctuary, Route 2, Kempton, Pennsylvania 19529. The final decision will be made by the Board of Directors late in 1983.

Only students enrolled in a degree-granting institution are eligible. Both undergraduate and graduate students are invited to apply. The award will be granted on the basis of a project's potential to improve understanding of raptor biology and their ultimate relevance to conservation of North American hawk populations.